

Operating characteristics of PNEUMATIC GRAIN CONVEYORS

By R. W. KLEIS

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Operating Characteristics of Pneumatic Grain Conveyors¹

By R. W. KLEIS, Assistant Professor of Agricultural Engineering

HANDLING FEED IS ONE OF THE MOST LABOR-consuming operations on the livestock farm. In recent years effort has been made to reduce that labor. The result has been the development of equipment such as silo unloaders, barn cleaners, feed blenders, elevators, conveyors, and feed distributors and dispensers.



Left: This blower in the grain storage building receives grain directly from an automatic grinder below it. *Right:* The 5-inch pipe (arrow) delivers the feed from the blower to the dairy barn, a distance of nearly 100 feet. (Fig. 1)

Despite these advances, however, little attention has been given to the problem of conveying prepared feed from the storage area to the feeding area of the farmstead. On an ideally arranged farmstead, this problem is not serious, since these two areas are sufficiently close to each other so that feed can be spouted or conveyed with short conveyors. But most livestock farms do not have an ideal arrangement, and much time and effort are involved in transporting feed. Pneumatic grain conveyors are being used now on some farms and do this job very effectively (Fig. 1).

Pneumatic systems have several advantages over mechanical conveyors that use chains, belts, or augers. Some of the more important ones are:

¹The investigation reported here was conducted as part of a cooperative project involving the application of electric power to farm operations and the reduction of farm chore labor. The cooperators were the Illinois Agricultural Experiment Station and the Agricultural Research Service, U.S. Department of Agriculture, and the project was supported in part by funds from Illinois electric power suppliers.

1. Simple construction. With only one moving part, servicing and maintenance problems are minimized.
2. The directing mechanism that, consisting of sheet steel pipe, is readily available and fairly inexpensive, even for long distances.
3. A flexible system that can include turns.
4. A lightweight pipe that can be suspended overhead and placed out of the way.
5. A system that can be made waterproof.
6. Lower initial cost than mechanical conveyors of equal length.

The one disadvantage of pneumatic conveyor systems is that they are less efficient than mechanical conveyors so far as power requirement is concerned.

Because pneumatic grain conveyors have been introduced on farms fairly recently, many questions arise concerning their application. To answer these questions, this study of the operating characteristics of long-distance pneumatic conveying systems was made, particularly to find out how they affect the design and operation of such systems. (*Long distance* is defined as any distance exceeding the span of existing farm elevators and mechanical conveyors, which is about 40 feet.)

The specific factors investigated were the effects of:

1. Pipe diameter on power requirement.
2. Pipe length on power requirement.
3. Pipe arrangement on system operation.
4. Conveying rate on power requirement.
5. Type of grain and fineness of grind on power requirement.
6. Conveying velocities on performance.
7. Pipe diameter on capacity.
8. Blower impact on grain-particle size.
9. Blowing on separation of grain at the terminal point.

APPARATUS AND METHODS

Commercial 16-inch and 19-inch diameter blowers were used for all tests. The pipe systems were of different lengths, varying from 65 to 220 feet, and of different diameters, 4, 5, and 6 inches. The elbows used were full-sweep elbows. Only one 90-degree elbow was included in most of the systems, but in some instances as many as three 90-degree elbows were used to determine what effect a greater number of elbows would have. Identical dust collectors, 20 inches in diameter, were used at the terminal points of all installations.

In all tests a Kewanee disk-type grain meter was used to meter the grain and ground feed into the blower. With this meter, the rate of feed was readily adjustable but was uniform at any setting.

To measure static and velocity pressures, an inclined tube oil manometer was used. Static pressure was measured both with and without grain flowing in the systems. Velocity pressure was measured only when the systems were empty. A pitot tube was used in conjunction with the manometer to determine velocity pressure. Atmospheric temperature, relative humidity, and barometric pressure were recorded in the test area so that air density could be calculated. This calculation, together with velocity pressure, was used to calculate air velocity.

The electric driving motor used for each test was mounted in a cradle-type dynamometer for the determination of horsepower. Standard dampened dynamometer scales and a recording tachometer were used in connection with the dynamometer to calculate horsepower.

To determine conveying rate, the grain meter was calibrated prior to the study. A rotap machine and test procedures recommended by the American Society of Agricultural Engineers were used to determine grain fineness for certain tests. All samples of grain were oven dried for the determination of moisture content.

DISCUSSION OF RESULTS

Effect of Pipe Diameter on Power Requirement

Typical test data plotted in Fig. 2 show considerable difference in power requirement between 4-inch and 6-inch diameter pipes. The major factors that contributed to this difference were air volume and static pressure. The air velocity necessary to convey any material is independent of pipe diameter. With the required conveying velocity, therefore, a 6-inch system has more than twice the volume of air flowing in it than a 4-inch system. If all other factors remain constant then, a 6-inch system requires over twice the power of a 4-inch system. As indicated in Fig. 3, however, a 4-inch pipe offers more static pressure than a 6-inch pipe. This has an opposite but lesser effect on power requirement than the air volume difference. Under similar operating conditions, the combined effects of greater air volume but lesser static pressure cause a 6-inch system to use about 50 percent more power than a 4-inch system. Five-inch systems require about 25 percent more power than 4-inch systems.

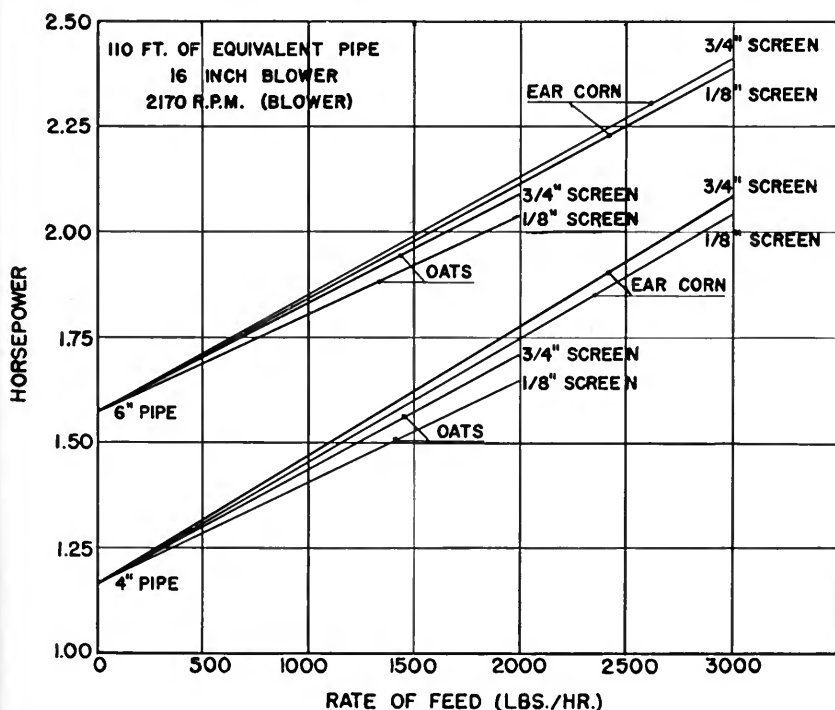
From the standpoint of power demand then, it is desirable to use the smallest pipe possible. Other factors, however, particularly conveying rate, determine the minimum allowable pipe diameter.

Effect of Pipe Length on Power Requirement

With a constant air velocity and a constant air volume, the static pressures of any two systems of equal diameter are directly proportional to the equivalent length of pipe in the systems involved. (*Equivalent length of pipe* includes the actual pipe length as well as the equivalent length of pipe of the dust collector, elbows, and adaptors.) Because power demand is proportional to static pressure, it is also directly proportional to the equivalent length of pipe in the systems involved. Theoretically then:

$$\frac{\text{equivalent length}_1}{\text{equivalent length}_2} = \frac{\text{static pressure}_1}{\text{static pressure}_2} = \frac{\text{horsepower}_1}{\text{horsepower}_2}$$

Results of these tests checked very closely with this theoretical relationship.



The effects of type of grain and fineness of grind on power requirement are small but consistent. Pipe diameter has a very significant effect on the power required for any given conveying rate. (Fig. 2)

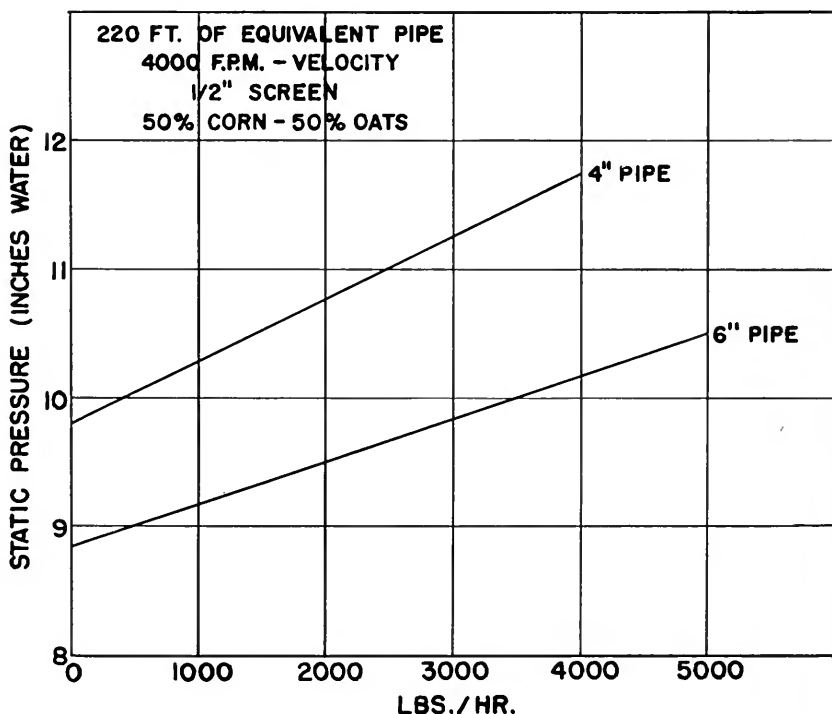
Effect of Pipe Arrangement on System Operation

Neither theory nor test results justify the popular belief that a sloping pipe has an efficiency advantage over a horizontal pipe. If friction losses are ignored, the energy required to move one pound of material from a given elevation to a higher elevation is the same, regardless of the path followed by the system. If friction losses are considered, the least possible length of pipe and the most direct path make for a minimum energy requirement.

Effect of Conveying Rate on Power Requirement

Two factors make power demand dependent on conveying rate: (1) the impact of grain upon the blower wheel, and (2) increased friction loss in the system due to the greater density of the grain-air mixture in comparison with air alone.

The effect of impact upon the blower wheel is entirely independent of length or diameter of system and type of grain conveyed, and can



Static pressure is substantially increased when either conveying rate is increased or pipe diameter is reduced. (Fig. 3)

be calculated for various rates of feed. Assuming for the moment that the grain takes on the same velocity as the conveying air, and knowing the air velocity, the power consumed by impact can be calculated by means of basic physical relationships. For an air velocity of 4,000 feet per minute, the power consumed by impact is .344 horsepower per 1,000 pounds of grain conveyed per hour.

As shown in Fig. 4, however, the increase of power requirement as the rate of feed was increased was slightly less than one-third horsepower per each 1,000 pounds of grain conveyed per hour. This indicates, as would be expected, that the grain does not take on as great a velocity as the conveying air. For purposes of practical design of systems, however, it may be assumed that the power required is increased one-third horsepower for each 1,000 pounds of grain conveyed per hour when the conveying velocity is 4,000 feet per minute.

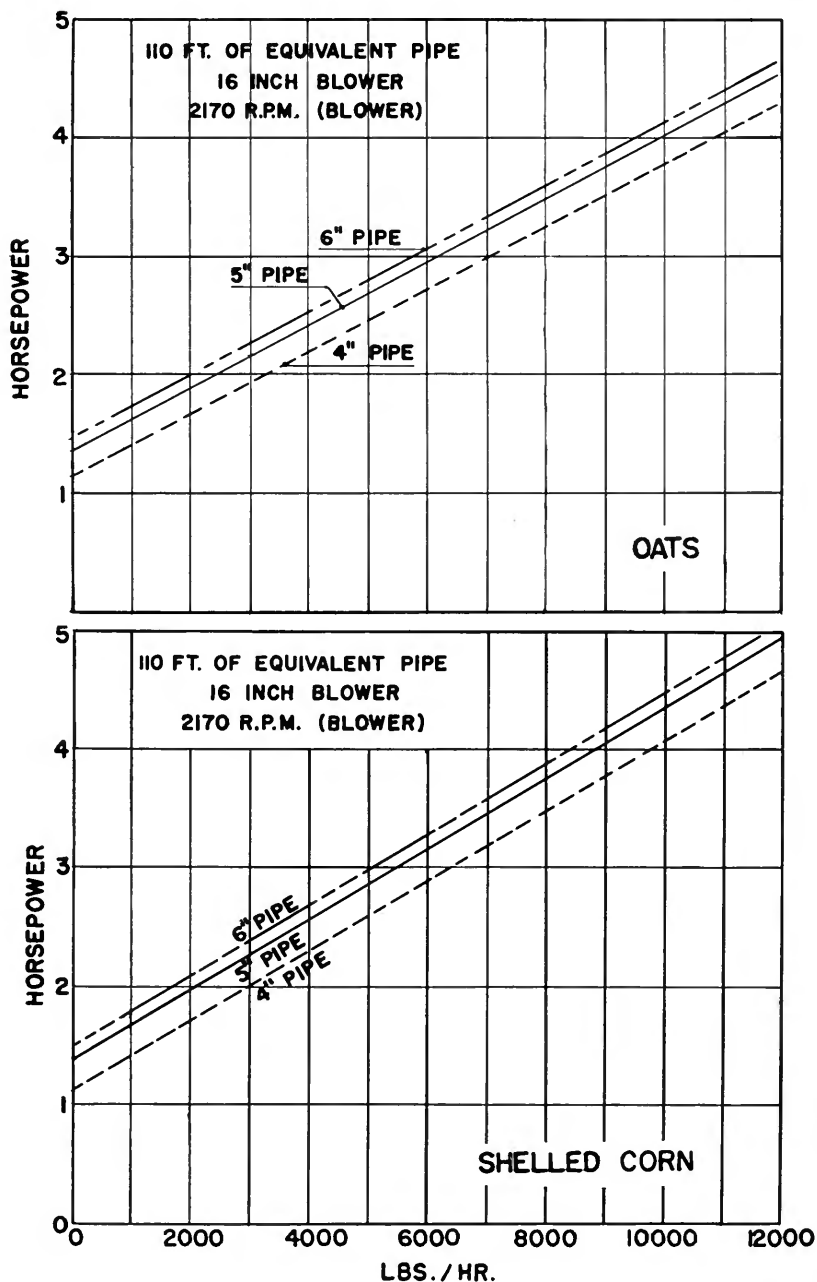
The effect of pressure differences caused by different densities of grain-air mixtures cannot be so easily calculated, but test results indicate that this effect, compared with that of impact, is small. Test data plotted in Fig. 4 indicate that static pressure and, in turn, horsepower are increased from 3 to 6 percent for each 1,000 pounds of grain per hour. This varies with the nature of the grain and the diameter of the pipe.

Effect of Type of Grain and Fineness of Grind on Power Requirement

The effect of various types of grain and fineness of grind on power requirement was tested by using whole oats, shelled corn, ground oats, ground ear corn, and a mixture of ground corn and oats. All comparisons were made on a weight rather than on a volume basis. The results of some of those tests are shown in Fig. 2. The differences in power requirement for the various grains were found to be consistent but small. In all cases denser materials required slightly more power than lighter ones.

The effect of fineness of grind on power requirements is also shown in Fig. 2. There was very little difference in power demand between ear corn ground through $\frac{1}{8}$ -inch and $\frac{3}{4}$ -inch screens. The difference was also slight when oats were ground through these two screens. In both cases, however, the differences were consistent.

If air velocity remains constant, type of grain and fineness of grind affect power demand only indirectly as they affect the friction loss of the system. In extreme cases, density affects the necessary velocity and, in turn, power demand. It is difficult, for example, to conceive of blowing whole ears of corn without a velocity much greater than 4,000 feet per minute — the velocity used in these tests. This would, how-



Power requirement increases as conveying rate of oats or shelled corn is increased. This power increase is independent of pipe diameter as shown by the fact that the three curves are parallel.

(Fig. 4)

ever, not be a significant factor for material commonly conveyed. In the design of a system, the fineness of grind has even less influence than the type of grain, and the effects of both are insignificant compared with those caused by other variables.

Effect of Conveying Velocities on Performance

Since velocity was a factor involved in every test, it was necessary to determine the optimum velocity early in the testing period so that it would be a fixed parameter in all subsequent tests. A velocity of 4,000 feet per minute was found necessary for satisfactory and trouble-free operation. This velocity is consistent with the recommendations of experienced field engineers.

In these tests it was observed that a velocity of 3,500 feet per minute conveys most grain. This velocity, however, once grain has been allowed to settle out of the air stream, does not clean the pipe. Grain will not settle in the pipe until the velocity has been reduced to about 3,300 feet per minute, and cannot be removed from the pipe until the velocity is increased to about 4,000 feet per minute.

Effect of Pipe Diameter on Capacity

For a fixed conveying rate and from the standpoint of power demand, the smallest possible pipe should be used. It appears that the minimum allowable air-grain ratio is 5 cubic feet of air per pound of grain. This means that for a given conveying rate there is a minimum diameter pipe that can be used without exceeding the desired air velocity or grain-air ratio. Expressed in different terms, there is a maximum quantity of grain that can be conveyed in a pipe of any given diameter. This theoretical maximum is about 4,000 pounds per hour for a 4-inch pipe and 9,000 pounds per hour for a 6-inch pipe.

In actual operation with existing equipment, however, the maximum conveying rate for a 6-inch pipe is considerably less than 9,000 pounds per hour. This is due to the fact that large amounts of grain tend to restrict the inlet area of the fan which, in turn, reduces the air velocity. Because this situation occurs in any current blower, it must be considered in the system design, unless blower designs are changed.

Effect of Blower Impact on Grain-Particle Size

Two series of tests were conducted to determine the extent of the reduction of particle size under different operating conditions. Some typical results of blowing at different blower speeds are shown in Table 1. (In all these tests, the grain was metered directly into the blower.)

Table 1. — Effect of Blower Speed on Reduction of Grain-Particle Size
(Conveying rate: 1,000 pounds per hour)

	Fineness modulus ^a of ground ear corn		
	Hammermill with ¾" screen	Knife mill with ½" screen	Burr mill
Before blowing.....	4.51	5.06	4.69
2,000 r.p.m.	4.22	4.67	4.38
2,500 r.p.m.	4.13	4.44	4.24
3,000 r.p.m.	3.92	4.17	4.14

^a *Fineness modulus* is an expression of grain particle size based on a test procedure developed at the University of Wisconsin and approved by the American Society of Agricultural Engineers as a recommended practice and procedure. The determination of fineness modulus is somewhat complex and involves special equipment, but some idea of its significance may be gained from the fact that flour has a fineness modulus of 0 and particles over ¾ inch have a fineness modulus of 7.

The particle size of the ground ear corn from each of the three types of mills used — hammermill, knife mill, and burr mill — was reduced considerably as it went through the blower. In all cases, greater blower speed caused greater size reduction. Size reduction was most severe in the corn ground with the knife mill, a result attributed to the sharp and irregular particles of grain resulting from this grinding method.

The effect of conveying rate on particle size reduction is shown in Table 2. The amount of particle size reduction decreases as conveying rate increases. This may be explained by the fact that at higher feeding rates a smaller percentage of the grain is subjected to direct impact with the blower blades.

When whole grain was used, at least 50 percent of the kernels of shelled corn were broken by the blower. Blowing whole oats likewise resulted in a considerable amount of hulling. It is clear, therefore, that pneumatic conveyors in which the grain is injected into the blower

Table 2. — Effect of Conveying Rate on Reduction of Grain-Particle Size
(Blower Speed: 3,000 r.p.m.)

	Fineness modulus ^a of ground ear corn		
	Hammermill with ¾" screen	Knife mill with ½" screen	Burr mill
Before blowing.....	4.51	5.06	4.69
1,000 pounds per hour.....	3.92	4.17	4.14
2,000 pounds per hour.....	3.99	4.32	4.25
3,000 pounds per hour.....	4.05	4.43	4.36

^a See footnote a to Table 1.

unit are unsatisfactory for conveying whole grain, unless the grain is to be fed to livestock.

Effect of Blowing on Separation of Grain at the Terminal Point

The separation of grain according to particle size as it is discharged from a conventional dust collector is usually considered a disadvantage of blower systems. The belief is that such separation is severer with blower systems than with other types of conveyors. Because little information existed on this point, a series of tests was conducted to determine the relative amounts of separation as grain is discharged from pneumatic-, belt-, and auger-type conveyors.

In these tests grain was allowed to fall freely a distance of 40 inches from the discharge point to a flat surface. Ear corn ground with a hammermill through screens of various sizes was discharged from each of these conveyors and allowed to accumulate in the form of a cone until its vertex was 20 inches high. Samples were then taken from equal concentric areas across the cone, and fineness modulus tests were run. (*Fineness modulus* is explained in footnote *a* to Table 1.)

Large amounts of separation occurred with all three types of conveyors, regardless of moisture content of the grain and fineness of the grind. As anticipated, the amount of separation decreased slightly as moisture content increased, and the finer the grind, the less was the separation. The most significant conclusion was that there was little difference among auger conveyors, belt conveyors, and blowers in amount of separation. Separation was almost identical in the auger and belt conveyors and only slightly greater in the blower. Compared with total separation in these tests, differences caused by fineness of grind, moisture content, and type of conveying system were insignificant.

SUMMARY AND CONCLUSIONS

This study of the operating characteristics of pneumatic conveyors for conveying grain and ground feed about the farm revealed the following:

1. A conveying air velocity of 4,000 feet per minute is necessary and sufficient for satisfactory and continuous operation.
2. The optimum pipe diameter for any pneumatic system is the smallest allowable for the desired conveying rate. The practical limits of conveying rates for common pipe sizes at a velocity of 4,000 feet per minute are:

4-inch pipe: 3,500 pounds per hour
5-inch pipe: 4,500 pounds per hour
6-inch pipe: 6,500 pounds per hour

3. The optimum pipe diameter for a pneumatic conveyor is not affected by the length of the system.

4. The power required to maintain an air velocity of 4,000 feet per minute without grain flowing in the system approximates:

1 horsepower for each 100 feet of equivalent length of 4-inch pipe

$1\frac{1}{4}$ horsepower for each 100 feet of equivalent length of 5-inch pipe

$1\frac{1}{2}$ horsepower for each 100 feet of equivalent length of 6-inch pipe

When grain is injected into the system, the power requirement is increased by about one-third horsepower for each 1,000 pounds of grain per hour.

5. Neither previous work nor the results of this study indicate any efficiency advantage to sloping the conveyor pipe in one direction or another. To facilitate drainage of moisture, however, the pipe should slope slightly toward the discharge end.

6. The arrangement of the pipe in a conveyor system should be such that no elbow is within about 20 pipe diameters of the dust collector.

7. Heavier grains as well as coarsely ground feed require slightly more horsepower for a given conveying rate than grains that are lighter or finely ground. These differences, however, are negligible so far as the design of a pneumatic system is concerned.

8. A considerable amount of reduction in particle size occurs when ground feed is run through a blower. This might well be considered in determining how fine to grind grain.

9. A considerable amount of separation occurs according to particle size at the discharge point of any type of conveyor. This separation is slightly greater with a pneumatic-type conveyor than with an auger- or belt-type conveyor, but the difference among them is extremely small compared with the total separation in all three types of systems.

10. Pneumatic conveyors are considerably less efficient than mechanical conveyors so far as power requirement is concerned. In other respects, however, the advantages of pneumatic conveyors are such that they constitute a practical solution to a great number of conveying problems.



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